Attachment No. 15

ANITA RESERVOIR

(Blaine County, Montana)

DAM FAILURE

Report by

Board of Inquiry

U.S. Bureau of Land Management

August 20, 1997

EXECUTIVE SUMMARY

On March 26, 1997, the Anita Reservoir dam embankment suffered major piping erosion along the outlet pipe. This resulted in the rapid discharge of almost 800 acre-feet of water through and along the outlet pipe in about 36 hours. This resulted in no injury or loss of life, and only minor property damage downstream, however four families evacuated downstream as a precautionary measure. The unusual spring flooding throughout the drainage presented much more serious risk of injury or loss than the failure of Anita Dam. (The drainage area into Anita Reservoir is only 4% of the East Fork of Battle Creek and about 1% of the total Battle Creek drainage.)

Anita Dam, located in the Havre Resource Area, Lewistown District about five miles from the Canadian border, was built under the Prairie Potholes Joint Venture with the U.S. Bureau of Reclamation and Ducks Unlimited. The dam was designed by BLM, and constructed by a contractor in 1996. Anita Dam is classified as a "Low Hazard" dam.

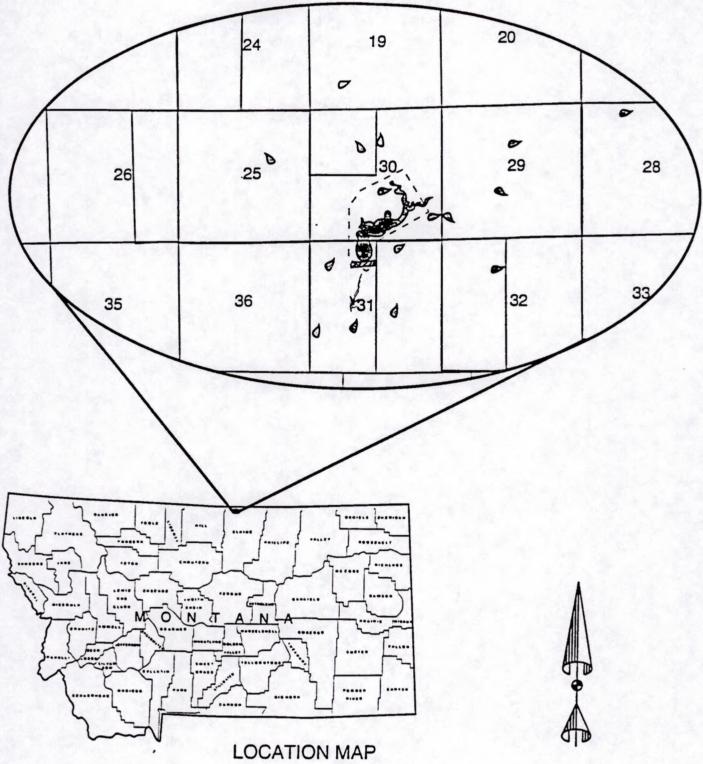
The reservoir is not on a live stream, and was anticipated to be filled over a three year period. But a large snowpack and warm weather throughout the area and into Canada caused the reservoir to be filled in only four days. Before the principal spillway (a standpipe) began flowing, water piped through the embankment along the outlet works and caused rapid failure of the dam. Although the embankment did not collapse, it was necessary to open the outlet gate and drain the reservoir. BLM personnel were on-site monitoring the situation until the reservoir was drained.

A Board of Inquiry was convened at the request of the BLM Montana State Director. The Board visited the site the week after the failure, and interviewed the people who witnessed the failure and participated in the emergency actions. Individuals involved in the design and construction process were also interviewed, and files were reviewed.

A series of soil samples from the dam area were tested, and a review of current dam design criteria was performed. The Board evaluated the criteria and procedures used by BLM personnel, as well as the effectiveness of the emergency actions taken in response to the developing failure. In addition, a literature search of previous dam failures nationwide was performed to compare similarities and causes.

The Board concluded that the cause for failure was piping, initiated by an small flow path along the outlet pipe through the dam embankment. This flow path need only have been a fraction of an inch, and could have been started by settlement, pipe rotation, freeze-thaw, or inadequate pipe compaction. It was discovered that the dam is constructed of a dispersive clay material ,which looks like "regular" clay material but goes into colloidal suspension in water and very rapidly loses cohesiveness. This both accelerated the failure and precluded the possibility of the piping void healing itself. The dam design lack redundancy to avoid this type of failure.

The dispersive clay problem can be remedied by adding calcium chloride to the soil, and/or by installing a sand filter in the embankment. These actions would preclude a similar failure.



Anita Reservoir & Satellite Ponds

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

REPORT OF DAM FAILURE

Structure Name: Anita Reservoir

Location: Lewistown District, Montana
(T. 37N, R. 19E, Section 31)

Date Constructed: November 1996

Date of Failure: March 26, 1997

Type of Failure: Piping through Embankment

BOARD OF INQUIRY

Name	Date
Larry Hoovestol Larry Hoovestol, P.E.	8/20/97
Owen Billingsley Owen Billingsley	8/20/97
James R Kor Jim Kor, P.E.	8/20/97
Lovell Parish Lovell Parish	8/20/97
Laurence Siroky Laurence Siroky, P.E.	8/20/97

PURPOSE OF THE BOARD OF INQUIRY

BLM Manual 9177, *"Maintenance and Safety of Dams"*, specifies Bureau policy and procedures for BLM-owned dams. Also, Handbook 9177-3, *"Reporting Dam Failures"*, outlines the process for investigating and reporting failures of BLM-owned dams.

As required, a Board of Inquiry was convened at the request of the BLM Montana State Director. The Board's responsibilities were to review the design and construction documents, investigate the dam site, interview involved individuals, request additional information and tests, evaluate data, review available literature about similar dam failures, and prepare a report summarizing their findings and conclusions.

The Board was composed of:

Larry Hoovestol, General Engineer (former BLM Dam Safety Officer); Chairman;
BLM - National Applied Resource Sciences Center; Denver, Colorado;

Owen Billingsley, Area Manager; BLM - Havre Resource Area Office; Havre, Montana;

Jim Kor, State Engineer; BLM - Wyoming State Office; Cheyenne, Wyoming;

Lovell Parish, Regional Geologist; Bureau of Reclamation; Billings Montana; and

Laurence Siroky, Bureau Chief, Water Operations (Dam Safety Officer);
Montana Dept. Of Natural Resources & Conservation; Helena, Montana.

Mr. Lovell Parish and Mr. Laurence Siroky were invited to participate on the Board to provide specific expertise to supplement that of the BLM employees. Mr. Parish was asked to review the geotechnical, soils, and construction inspection portions of the project, and Mr. Siroky was asked to review the project as it relates to non-Federal dams in Montana and the Montana Dam Safety Program.

Both individuals provided valuable expertise and insight to the Board as they reviewed and evaluated possible causes of failure. It must be noted that they represented their individual areas of expertise, and were not formally representing their respective agencies in the preparation of this report.

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(* Appendices are available upon request from the BLM Montana State Office)

BACKGROUND

Three of the Resource Areas (RA's) in the Lewistown District, i.e., Havre RA, Phillips RA, and Valley RA, contain 1.75 million acres of public land in the Milk River Basin. Bureau of Reclamation appropriated the vast majority of the water rights in the Milk River Basin by 1924; thus BLM water rights were fairly limited to begin with and have already been used.

The BLM, Lewistown District, needs to develop surface water to carry out the agency's multiple use management responsibility for the BLM administered land in the Milk River Basin between Fresno and Vandalia. BLM entered into an MOU with the Upper Missouri Region of the BOR in September, 1981; which allowed BLM to construct surface water developments in the Milk River Basin above Vandalia Diversion Dam. The MOU allowed BLM to construct stockwater pit-type reservoirs of less than 2 acre-feet capacity without consulting BOR. Any structure capable of storing 2 acre-feet or larger needed BOR approval before construction.

This 2 acre-feet limitation severely hampered BLM's involvement in the prairie Potholes Joint Venture; an agreement among governmental agencies for the enhancement and construction of waterfowl habitat structures in north central and north eastern Montana. Many of these structures required a capacity greater than 2 acre-feet to be an effective waterfowl rearing habitat. The MOU also restricted BLM's development of recreational waters in the Milk River Basin.

In the spirit of cooperation, the two agencies revised the MOU effective September 1992. This new MOU allows BLM to construct up to 1,000 acre-ft of non-releasable storage per year, not to exceed 3,500 acre-feet in the five year period 1992 through 1996. In return, BLM must provide 1 acre-foot of releasable storage for every 6 acre-feet of non-releasable storage constructed elsewhere in the basin.

The only constraints are that BLM must monitor and record the reservoir level, obtain inflow data and release water when required by BOR within seven days of being contacted to do so.

In 1993, BLM in Montana, Colorado, and Wyoming entered into an Interagency Agreement with the BOR, Great Plains Region, to jointly plan and fund riparian-wetland enhancement with emphasis on waterfowl. The Anita Reservoir project is a pilot project under that Interagency Agreement.

Anita Reservoir is located about 22 miles north and slightly west of Chinook, Montana in northern Blaine County, about 5 miles south of the Canadian border. The legal location of the dam is T.37N., R.19E., Sec. 31, NW 1/4. The drainage, which normally flows water only in response to snowmelt or heavy rain, is an unnamed tributary of the East Fork of Battle Creek, which flows southward into the Milk River.

Anita Dam was assigned a "Low Hazard" rating (consistent with the Department of Interior criteria), with the nearest potentially affected downstream resident being nine miles away. The closest population centers in the vicinity are Chinook, Montana, about 22 miles south, and Havre, Montana, located about 60 miles southwest of the site.

This is a landmark project in that BOR agreed to share funding for a project that is administered by BLM. Funds were provided by the BOR, Ducks Unlimited, Pheasants Forever, Montana Department of Fish, Wildlife and Parks, and BLM. Over $100,000 was provided from sources outside of BLM.

The reservoir will be used as a waterfowl production area and releasable storage site. The only requirements for beneficial water use are that Anita Reservoir contain a release structure which is, at a minimum, 36" in diameter; only divert that water which is unappropriated; and submit (to Bureau of Reclamation) mean monthly inflow and outflow by November 30 each year.

Fifteen satellite ponds will be located within 6 miles of Anita Reservoir and the system will make up what will be known as the Mathiot Waterfowl Complex. While significant waterfowl/wildlife habitat and recreation opportunities will be provided by the reservoir, the overriding benefit is the opportunity, through the MOU with BOR, to allow water development to proceed elsewhere throughout the Milk River Basin.

PROJECT INFORMATION

Reservoir Data:

- Watershed area is approximately 10,100 acres
- 77 surface acres inundated; maximum depth of 30 feet (at principal spillway)
- Impoundment will hold 794 acre-ft. -- Releasable storage of 769 acre-ft
  -- Dead pool of 25 acre-ft

Hydrologic Data:

- Approximately 372 acre-ft mean annual yield
- Approximately 36 cfs full bank stream flow below reservoir

Embankment Data:

- Compacted earthen dam, approximately 64,607 cy
  (1,012 feet long; 42 ft. maximum height; 14 ft. wide crest)
- 3:1 front and backslopes, 6 ft. of freeboard to west spillway
- 2 natural spillways, east and west side (300 ft. wide)
- 1.5 ft. rock riprap on front slope up to emergency spillway
- Core trench, 12 ft wide at bottom
- 48" primary spillway riser, 36" drawdown pipe with gate, 42" outlet barrel
- Gabion outlet basin and toe drain
- Cathodic protection

Project Cost:

- Approximately $430,000

DESIGN AND CONSTRUCTION PROCESS

Preconstruction Geotechnical Investigations

Preconstruction geotechnical investigations for Anita Dam were conducted between 1993 and 1995. They were completed in four general areas - the dam proper, the main borrow area, a potential borrow site immediately east of the dam, and miscellaneous potential borrow sites west of the reservoir. The sites were explored with shallow test pits excavated by backhoe. Each pit was field-logged using the Soil Conservation Service agricultural classification system. Proctor compaction tests were completed using samples from several test pits where the material appeared suitable for impervious fill, and numerous Troxler densities were conducted in the pits.

Investigations in the vicinity of the dam consisted of a total of 10 test pits varying in depth from 8 to 13.5 feet. Eight of the pits were located roughly along the alignment of the axis, and one pit was located upstream from the axis and one downstream - each near the maximum section. The field logs did not use the Unified Soil Classification System, which is the standard system of classification for engineering materials investigations, so it is quite difficult to correlate those logs with laboratory test classifications. It appears that the alluvial and glacial deposits of the valley floor consist of a highly variable mixture of sediments. The field logs indicate material varying from heavy, fat clay to sand and gravel. It should be noted that the classifications do not seem to agree with other laboratory soil classifications of material from the same area, and may represent visual rather than laboratory-classified material.

No deep drill holes were completed at the dam site; the deepest test pit was 13.5 feet. Deeper holes with standard penetration tests (SPT) and percolation (water loss) tests would have been very useful in determining the depths, physical characteristics, bearing capacity, and water-holding ability of foundation materials.

Reconnaissance investigations for construction materials were initially conducted over a wide area, as would be expected, with preconstruction exploration eventually being concentrated in the borrow area that was finally utilized for impervious fill. Nine shallow test pits were excavated by backhoe in the general area. They varied in depth from 6.0 to 13.5 feet. Most of the materials encountered and tested were classified as CL (either Lean Clay With Sand or Sandy Lean Clay).

The number and depths of test pits in the borrow site were probably adequate to determine materials in this instance, but complete gradations and hydrometer testing should have been obtained to determine the full range of particle sizes of materials from clay through gravel. Those tests would have given a better indication of the homogeneity of materials in the borrow area, and thus whether special mixing would be necessary if differing units were encountered.

Design

The design was performed at the District Office under the direction of, and reviewed by, a Professional Engineer, and received a technical review at the BLM State Office.

The hydrologic design was based on extensive research. The district staff used National Weather Service, SCS, and USGS rainfall and runoff data as a basis for calculating annual and event runoffs. The design calculations were based on a 100-year storm. This was an adequate storm frequency on which to base the design because the two natural emergency spillways are 300 feet and 70 feet wide. The Probable Maximum Flood would pass through these spillways without causing a problem. The principal spillway pipes and the natural emergency spillways were adequate to handle the anticipated runoff event with no damage to the structure.

The spacing of the concrete cutoff collars was calculated using standard procedures. The cutoff collars were designed to increase the travel path length along the pipe by 20%, in accordance with the "Design of Small Dams" book (1977 edition).

The District took soil samples with a backhoe in both the borrow pit and under the proposed embankment. The use of the backhoe for taking the samples limited the maximum depth of sampling to about 13 feet. They had a soils laboratory perform Atterburg limits and standard proctor density tests. The soil sampling method and depth of sampling are standard for BLM dams.

The earthwork specifications were the standard BLM specifications for a watered and rolled earthen dam. The pipe, weir, and flume specifications were somewhat unique to this project, but they were well researched and written. The drawings were complete and provided all the information necessary for the contractor to perform the construction and assembly of the embankment, pipes, weirs, and the Parshall flume. Major portions of the specifications were changed after the bid package was advertised, but prior to awarding the contract. This indicates that the District was continually reviewing their work and responding to questions by contractors.

Construction Inspection (Quality Control)

Review of the voluminous inspectors' reports and interviews with the contractor and inspectors indicate that the quality control during construction was exceptional. The contract diary was complete. The daily diaries give a good running account of the construction progress, problems encountered, how the problems were solved, and all discussions with the contractor. The project inspectors should be commended on their thoroughness in keeping the contract diary.

All submittals were reviewed by the Government and any discrepancies from the specifications were corrected prior to installation. Throughout the construction process, the contractor had to perform more work than he had anticipated to meet the moisture and density requirements of the specifications (95% of the maximum dry density with the moisture content within plus or minus 1% of optimum). The nuclear density machine test reporting sheets show that literally hundreds of test were taken on the embankment during construction.

When the investigation team met with the contractor, he probably paid the inspectors his highest possible compliment when he said that he thought that they were nearing the point of "harassment" with their testing and inspections; but that after the failure, he sure was glad that they had done their job so well. In turn, during interviews, the inspectors stated that they felt that the contractor's operations often exceeded their expectations.

FAILURE OF ANITA DAM

Sequence of Events

Rapid snow melt between 3/20 and 3/26 in the uplands caused heavy runoff in southern Saskatchewan and north Blaine County, including large flows down this drainage and into the reservoir. Roads to the reservoir site were washed out before March 26.

Mr. Chris Gorder with XENO, Inc., trying to reach nearby natural gas wells to perform regular service, noticed a leak beside the outlet pipe during the morning of 3/26. Mr. Gorder immediately notified Disaster and Emergency Services (DES) of Blaine County. DES in turn contacted BLM. BLM dispatched Herb Chavez, Civil Engineer, and Larry Birdwell, Civil Engineering Technician to the site (afternoon of 3/26) to relieve Claire Moxley, Incident Commander (IC) for Blaine County. They arrived at approximately 1800 hours and began a coordinated effort with the Blaine County Commissioners, Sheriff, and Disaster and Emergency Services coordinator in Chinook.

Initial data collected showed approximately 700 acre-feet of water stored and a high leakage rate the evening of 3/26 which raised concerns of the possibility of catastrophic failure. BLM's Mike Montgomery (District Engineer), Greg Bergum (State Engineer), and Carl Patten (Civil Engineer) reviewed the situation and contacted DES late in the evening of 3/26 about data reflecting a possible risk of catastrophic failure of the embankment. BLM continued to monitor the situation and kept the County informed.

Because of the possibility of a dam failure and the ensuing flood crest of water, late on 3/26 DES notified about 19 families living within 22 air-miles downstream of the structure of the possible need to evacuate. According to information from the Blaine County DES office, four families (3 owners, 1 renter) did evacuate their homes.

Mike Montgomery and Greg Bergum arrived on site and Mike assumed the role of Incident Commander on site the morning of 3/27. The drainage was flown by helicopter and Greg Bergum video-taped the drainage from Anita Reservoir to the Milk River.

A local National Guard unit was activated by DES on 3/27 to control traffic on local roads and to assist with evacuations if necessary. The Guard unit was demobilized on 3/28. A Type II Incident Command Team was requested by BLM and arrived in Chinook late on 3/27. The Incident Team provided financial and public contact assistance to BLM and DES, and completed its work with a closeout on 3/29.

Throughout the day, 3/27, measurements showed inflow decreasing and outflow stabilizing somewhat. The total flow out of the reservoir increased during the day as both the leak and outlet pipe flowed heavily. The overall situation improved due to the fact that water was released faster than runoff flowed into the reservoir. The reduced amount of water behind the embankment and corresponding lower water level reduced risk of catastrophic failure.

Data collected at 1530 hours showed water stored in reservoir had been reduced to 364 acre-feet with an inflow of 28 cubic feet per second (cfs) and an outflow 334 cfs. Data collected at 1830 hours showed water stored at 276 acre-feet with an inflow of 25 cfs and an outflow of approximately 400 cfs. The reservoir showed multiple (20) vortexes formed about 150 feet upstream from the dam.

BLM kept two employees at site until the reservoir was completely drained, which occurred the morning of 3/28. The only water left in the reservoir was minimal storage below the outlet pipe. All water coming into the reservoir was flowing out through the damaged area along the outlet pipe.

Residents had not yet returned to their homes on the morning of 3/28 due to high water caused by rapid melting in Canada unrelated to the condition of Anita Dam. DES later determined it was safe for them to return.

The BLM officially notified Blaine County the afternoon of 3/28 that the reservoir no longer posed a threat.

Agency Roles

During the period of concern about failure of Anita Dam (3/26 to 3/28), the Blaine County DES office and the BLM each had lead responsibility for handling different aspects of the situation. The dam leakage occurred in a time period when many creeks and the Milk River itself were running high and causing local flooding. Because of the local flooding context, Blaine County was already operating in an emergency mode when notified of the Anita Dam problem.

The County Commissioners, Sheriff, and DES coordinator were handling, and continued to handle, the aspects of the overall situation dealing with public and media information, and with warnings and possible evacuations. The BLM role was limited to evaluating the Anita Dam - its condition, rate of water release, and forecasts about its threat of sudden failure. BLM staff at the dam site and in the Lewistown dispatch office performed critical functions and relayed information about these to County officials:

1. Onsite reporting beginning late afternoon 3/26 on the condition of the dam itself and the rates of inflow and outflow.

2. An estimate of the downstream consequences of total failure of the structure with sudden release of all stored water.

3. Notification to the County when the reservoir was emptied and no longer posed any threat.

4. Standby assistance in the event that the dam were to fail catastrophically.

Late during this incident, several other roles developed for the BLM:

1. When BLM authority was delegated to the Type II Incident Team, the Team had a limited role in BLM-County coordination, although this occurred in the final stages of draining the reservoir. The team provided onsite payment for some expenses incurred by the County, and gathered information from the County to expedite future payment actions. They also assessed the information flow between the County and BLM and provided some recommendations.

2. Identification of a focal point in the BLM for media contact (External Affairs, MSO) and issuance of press information related to the condition of the dam.

Communications

Communication occurred in several ways between various offices and agencies: telephone land lines, cellular telephones, and BLM radio net. Initial contacts between the County and BLM occurred mainly between the Lewistown Dispatch station and County officials (Commissioners, DES coordinator).

Those contacts led to notification of the State Office and Washington Office of the BLM in the following sequence, based on logs from the Lewistown District Office (LDO) and other staff who were involved. Not all contacts are listed here, but only those that represent first notifications and major situation updates.

Date	Time	Nature of contact
3/26	0930	First onsite observation of leakage by Chris Gorder, Xeno, Inc.
3/26	1115	Chris Gorder calls Claire Moxley about leakage.
3/26	1130	Carl Patten, Herb Chavez, engineering in LDO notified by Moxley (Contractor and County Commissioner) that piping may be occurring around outlet pipe.
3/26	1300	Initial request for helicopter made to Bruce Reid, LDO Fire Control Officer by LDO engineering.
3/26	1300-1430	Greg Bergum, State BLM engineer called by LDO advising him that leakage is occurring.
3/26	1510-1530	LDO dispatch office becomes operational.

3/26 1600 Dave Mari, LDO District Manager (in Billings for a meeting) is briefed by phone by Jim Feist, LDO Assistant District Manager - Support Services.

3/26 2330-2400 BLM engineers estimate magnitude of potential flood crest if dam failed catastrophically and notify Blaine County DES.

3/27 0130 Downstream residents notified by Blaine County Sheriff's office of possible evacuation.

3/27 0530 Status report by telephone from Greg Bergum to Janet Singer (Deputy State Director, Division of Support Services).

3/27 0800 Phone briefing of Larry Hamilton, BLM State Director by Jim Feist.

3/27 0900 Initial Washington Office notification (Tom Fry by Larry Hamilton). Barbara David of WO Protection and Response Group notified.

3/27 0900 BLM Dam Safety Officer notified of situation by Barbara David.

3/27 0900 Phone briefing of Dave Mari and Gene Miller, Associate District Manager, by Jim Feist.

3/27 1100 Conference call with Larry Hamilton and staff to discuss overhead team, public information, etc.

3/27 1240 Early alert memo sent to Gwen Mason, Bob Johns and Celia Boddington of the External Affairs staff, and Mike Blymyer of the budget staff (all in the Washington Office). It was also sent in Montana to Bob Haburchak, Ann Boucher, Greg Albright, Janet Singer and Nelda St. Clair (all in the Montana BLM organization).

3/28 1310 An updated early alert was sent to Dave Mari, Fran Cherry, Greg Albright, Janet Singer, Larry Hamilton, Tom Lonnie, Trudie Olson, Celia Boddington, Mike Blymyer, Barbara David, Bob Johns, Gwen Mason and Hord Tipton.

During the time spanned by this brief chronology, many other contacts were made and information passed on about the Anita Dam situation. The radio contacts were recorded in the Dispatch logs, but telephone and in-person communication were not logged. (With cellular phones, land lines, and multiple offices involved, logging all communication was not practical.)

INVESTIGATION OF FAILURE

Site Visit and Interviews

The Board of Inquiry convened on April 2, 1997 on-site at Anita Reservoir, and investigated the dam site and failure area. The piping next to the outlet pipe was visually inspected, and the upstream and downstream areas were inspected.

On April 3, the Board interviewed witnesses to the failure, and individuals involved with the design and construction of the dam, and others involved with the emergency actions.

Individuals interviewed included:

Mr. Chris Gorder	Xeno Inc.	First on scene/reported incident
Mr. Claire Moxley	Blaine County (County Commissioner)	Second on scene/opened gate
Mr. Ralph Page	BLM Havre R. A.	Took first video of failure
Mr. Marty Dirden	Blaine County (Emergency Coordinator)	Coordinated evacuations
Mr. Herb Chavez	BLM Lewistown D.O.	Design Engineer
Mr. Mike Montgomery	BLM Lewistown D.O.	Design oversite/monitored failure
Mr. Greg Bergum	BLM State Engineer	Design review/monitored failure
Mr. Dan Moxley	Moxley Construction Co.	Construction Contractor for Anita
Mr. Larry Birdwell	BLM Lewistown D.O.	Construction Inspector
Mr. Ken Koncilya	BLM Lewistown D.O.	Construction Inspector

As a result of these interviews, the design criteria were determined, the construction and inspection process was assessed, and the nature of the failure, and emergency actions were reviewed.

The Board decided to perform a review of the design, soils investigation, construction inspection diaries, emergency actions taken, communications during the incident, current design standards, and a literature search of similar dam failures.

INVESTIGATION OF FAILURE

Site Visit and Interviews

A site inspection was conducted on April 2, 1996, at Atlas Rose [illegible] failure area. The pipeline next to the [illegible] was visually inspected, and its condition and [illegible] were inspected.

The [illegible] also held interviews with [illegible] the failure [illegible] involved with the design and construction [illegible] incident, and [illegible].

Individuals interviewed included:

Mr. Gary Conner	Kane Inc.	[illegible] incident
Mr. Glenn Moxley	Blaine County (County Commissioner)	[illegible]
Mr. Ralph Page	BLM [illegible]	Technical [illegible]
Mr. Mary Dixon	Blaine County (Emergency Coordinator)	Coordinated evacuation
Mr. Jack Chavez	BLM Shoshone D.O.	Design Engineer
Mr. [illegible]	BLM Shoshone D.O.	Design oversight, [illegible] failure
Mr. Greg [illegible]	BLM State Engineer	Design [illegible]
Mr. [illegible]	Mountain Construction Co.	Construction Contractor [illegible]
Mr. Larry [illegible]	BLM Shoshone D.O.	Construction [illegible]
Mr. [illegible]	BLM [illegible] D.O.	Construction inspector

As a result of these interviews, the design, [illegible] the construction and inspection process were assessed, the [illegible] of the failure, and emergency [illegible] were [illegible].

The team decided to perform a review of the [illegible] investigation, [illegible] construction, emergency action plan, communications during the incident, [illegible] standards, and [illegible].

Review assignments were:

- Design Criteria	Jim Kor
- Soils Investigation	Lovell Parish
- Inspection Diaries	All members
- Design Standards & Literature Search	Laurence Siroky and Larry Hoovestol
- Emergency Actions & Communications	Owen Billingsley

Theories and Additional Tests

Several theories were developed and discussed by Board Members to try to explain the events leading to the failure of Anita Reservoir. The initial theories were:

- Freeze-thaw action along the pipe, created by several weeks of - 40° temperatures, which created an annulus of moisture along the pipe and served as the initial conduit for water to flow;

- The interface of the hand compaction area next to the pipe and the machine compacted area away from the pipe, which created a seepage path;

- Inadequate adhesion of the compacted soil with the epoxy-coated pipe, which, possibly coupled with freeze-thaw action, could have created a flow path; and

- The presence of a dispersive material, which would greatly accelerate any flow path, resulting in rapid catastrophic failure.

Specific follow-up actions were discussed and the Board decided to request additional soil samples and laboratory tests from the dam embankment and borrow area.

The first phase involved excavation along the outlet pipe with a backhoe. Geotechnical experts observed this activity and gathered material samples from this area, and investigated the borrow area and gathered soil samples from there.

The second phase was to have the Bureau of Reclamation conduct borings along the embankment and next to the outlet pipe to determine the composition of the embankment materials and to gather further information about the foundation material. This involved drilling a total of 5 holes to maximum depths of about 100 feet in the embankment and foundation of the structure to determine the characteristics of both the embankment and foundation materials. Four of the holes were drilled along the dam axis and the other upstream near the vertical risers for the valve control structure and the principal spillway.

Review assignments were:

- Design Criteria — Jim Hall
- Failure Investigation — Lowell Pauls
- Construction [illegible] — [illegible]
- Design Standards & Literature Search — Literature survey [illegible]
- Emergency Actions & Communications — [illegible]

Theories and Additional Tests

Several of the theories were developed and discussed by Board Members to try to explain the mechanism leading to the failure of [illegible] Reservoir. They include the following:

- Frost penetration along the pipe, [illegible] several of the [illegible] temperatures, which created an annulus of moisture along the pipe and [illegible] for water to flow.
- The absence of the [illegible] compaction adjacent to the pipes and [illegible] compacted [illegible] away from the [illegible], which created a seepage path.
- Inadequate compaction of the compacted soil with the [illegible] pipe, possibly coupled with freeze-thaw action, could have created [illegible].
- The presence of a dispersive material, which would [illegible] resulting in rapid catastrophic failure.

Specific follow-up [illegible] were [illegible] and the Board decided to [illegible] additional soil samples and laboratory tests from the dam embankment and borrow area.

The first phase involved excavating along the outlet pipe with a backhoe. Geotechnical [illegible] observed this activity and [illegible] samples from the area and investigated the [illegible] samples from there.

The second phase was to have the [illegible] conduct [illegible] along the embankment and [illegible] the outlet pipe [illegible] about 75 [illegible]. This [illegible] a total of [illegible] to the [illegible] of about 100 [illegible] and the [illegible] foundation [illegible] to [illegible] the embankment and [illegible] were [illegible] the [illegible] for the valve [illegible] respectively.

Laboratory tests for unit weight, moisture content, gradation, soil type, and for dispersive characteristics were performed at private materials laboratories in Billings.

CONCLUSIONS

Anita Dam

The physical cause of the dam failure was a pipe void likely completely through the dam that was created by one or more mechanisms discussed later in this section. Based on the results of the laboratory soil tests and the literature searches, the most probable cause of failure of Anita Dam was the presence of dispersive clay materials in the embankment. The dispersive nature of the soils accelerated the failure and eliminated the possibility of the piping void healing itself.

This dispersive material can only be detected by laboratory tests, and was not previously known to be present in this area of Montana by any of the Board members. It appears to be a "normal" cohesive clay material, which is desirable for embankment dams. However, when it is subjected to water, this dispersive soil goes into a colloidal suspension and loses all cohesiveness. This unusual characteristic was only discovered in the 1970's.

The usual lab test for this material involves compacting the soil, and then poking a 1 mm hole in the sample and subjecting it to a 2 inch head of water. A cohesive material does not experience any change, but a dispersive material immediately erodes along the pinhole, and may totally dissolve.

The material samples from along the outlet pipe and from the borrow pit all exhibited dispersive characteristics.

Literature describes many dams which have suffered rapid failure upon initial filling. The usual scenario is an embankment (which is later determined to contain dispersive soils) which has only a small flow path, but fails in a matter of hours. The flow path would usually swell shut in normal cohesive materials, but immediately erodes in dispersive soils. The result can be a piping cavern which leads to rapid failure of the dam.

Anita Dam failure exactly fits the description of this type of failure.

In addition, current design technology for bedding pipes through dam embankments, the design and installation of filter systems (instead of cutoff collars) around outlet pipes, and redundancy of design to avoid piping failures were not adequately incorporated into the design for Anita Dam, and may have contributed to the failure.

It is unknown what caused the initial flow path at Anita Dam. The likely causes are:

- Freeze-thaw along the pipe. This is very probable, because of the moisture content of the soil (17%) and the long stretch of very cold weather. The soil froze along the top of the embankment, and several areas of frozen material were observed when the area along the pipe was excavated with the backhoe. The fact that the reservoir was empty and the outlet pipe was open to the air would have caused the material along the pipe to also freeze. With the 100° + change in temperature from summer (when the pipe was installed) to winter, the pipe would have experienced a change in circumference of about 1/4 inch -- enough to create an initial flow path.

- Compaction interface between different methods of compaction. This interface was in the same location from the pipe all the way through the embankment. This could have created a slippage plane of under-compacted material which could have caused a weaker area for erosion.

- The "slick pipe". An epoxy-coated pipe was used to resist corrosion from the soils. This could have hindered adhesion with the compacted soils around the pipe, and helped establish the flow path.

Other possible causes for the flow path were also evaluated. These include:

- The location of the anode holes parallel to the pipe (for corrosion resistance) may have created a weak plane. This is an unlikely cause because of the small size of the vertical holes (6" x 2') and the distance between the holes.

- Compaction under the pipe may not have been adequate, because compacting materials under the haunch of a pipe is difficult. Construction reports indicate that adequate compaction was achieved. (Follow-up tests indicated the compaction may have been less than 95% of Proctor.)

- Rotation of the outlet pipe from unequal embankment weight on different segments. The differing alignment of the outlet pipes (both horizontally and vertically) is unusual for dam outlets. Unequal vertical loads and possible differing settlement due to varying underlying fill material could have caused rotation of the outlet pipe. This could cause unequal stress along the pipe, possibly creating minor voids along the pipe.
(This should be analyzed if the dam is to be rebuilt using this outlet configuration.)

- Settlement along the pipe caused by shear cracks above the side slopes of the cutoff trench for the outlet pipe and a "bridging over" of the embankment material caused by differential settlement. This is possible, but more likely to be evident along the cutoff trench parallel to the embankment (perpendicular to the pipe) because of the relative size of the cutoff trenches.

- Rodent hole into the embankment could have caused piping. This is very unlikely, because the embankment was finished in November, and no holes were noticed in January when the riprap was placed in the area of failure. It is doubtful any burrows would be dug during the cold of winter into frozen material.

Because all of the material along the piping area has been washed away, the exact origin of the piping path cannot be determined. It is very probable that the flow path could have been established by a combination of these conditions. While the exact cause of the flow path may never be established, this is not viewed as critical by the Board, because the methods of designing protective measures for these conditions are virtually identical.

The solution is to address the problem with the dispersive soils. If the soils had not been dispersive, probably none of the likely causes of the flow path would have caused failure. Usually these types of flow paths only cause very small flow paths, which would normally become closed as the material has time to swell when wet, and in effect, heal themselves. In this case, the dispersive nature of the soil both accelerated the failure and precluded the piping from healing itself.

The second phase of the soils investigations revealed some soft layers in the foundation. These don't appear to have contributed to the failure, but should be evaluated if the dam is to be rebuilt.

Bureau wide Dams

The failure of Anita Dam has raised several questions regarding BLM's dam design criteria and standards. Although Anita Dam was generally designed in accordance with traditional BLM standards, the subsequent review has brought to light several areas which need to be updated.

Some specific areas noted are:

- Need for better preconstruction geotechnical investigations, including foundation information and soil test data -- especially for potentially dispersive soils!

- Need for current design criteria and standards, such as elimination of cutoff collars on outlet pipes (which Bureau of Reclamation did several years ago), and instead, adding a filter blanket at the downstream end. This eliminates the problem with hand compaction around the collars.

- Need for current design techniques for bedding under outlet pipes, such as soil-cement or concrete slurry to eliminate compaction problems in this area.

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Sundays 'la Boca'

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- Need to [illegible] [illegible] [illegible] and [illegible] [illegible].

- Need for [illegible] design [illegible] and [illegible] [illegible] [illegible] several years [illegible] [illegible] [illegible] [illegible] around the [illegible].

- Need [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] this area.

- Need standards for proper treatment of problem soils, such as adding lime or calcium chloride to dispersive soils, and/or adding a sand filter blanket on downstream end.

- Need to carefully evaluate the potential hazard from the new dam, including downstream inundation mapping, and to coordinate with local officials.

- Need to update and reinforce procedures related to the Dam Safety Program, and to clarify lines of communication and responsibilities.

RECOMMENDATIONS

Anita Dam

In addition to the soils investigations and laboratory tests, a very careful excavation of the outlet pipe should be conducted. Personnel familiar with the structure and its construction, and knowledgeable of the various theories of failure proposed by the Board of Inquiry, should be present throughout the procedure to look for any evidence of a failure mechanism that might be uncovered.

If the final decision is to reconstruct the dam, the latest design criteria and construction procedures should be followed for structures containing dispersive clays.

The results of the soils investigations should be analyzed to determine if any of the information about the embankment or foundation conditions would influence a decision to redesign and reconstruct the dam.

The design should incorporate appropriate redundancies to address the probable causes of failure detailed in this report.

Any redesign of Anita Dam should include an analysis of the unusual configuration of the outlet works. The pipe joints should be included in the analysis to account for any anticipated settlement or rotation.

The outlet pipe (without cutoff collars) should be bedded in a slurry of soil-cement or concrete up to the middle of the pipe; and compacted over the remainder of the pipe with pneumatic tired equipment until a sufficient amount of cover is achieved; and a filter and drainage system installed around the lower portion of the pipe to control any seepage and piping of dispersive materials.

For extra safety, a complete filter blanket with toe drains should be constructed on the downstream face of the dam, and all material used for reconstruction (especially around the outlet pipe) should be treated with calcium chloride or some other suitable substance to help alleviate the dispersive properties of the local soils.

Above all, we recommend a thorough peer review of the final design by someone familiar with the problems caused by dispersive soils, and experienced with dam filter blanket design.

Bureau wide Dams

Current design criteria for BLM dams needs to be updated. The Engineering Advisory Team should designate a Work Group for reviewing and evaluating "state-of-the-art" dam design criteria (primarily Bureau of Reclamation). This should be done in early FY 1998, and issued to the field soon thereafter.

A list of required and recommended soil tests should be developed, and laboratory tests for dispersive soils needs to become a standard procedure. This is a cheap investment to avoid a duplication of the incident at Anita Reservoir.

Downstream inundation areas need to be determined for every new dam to assign the appropriate hazard rating, and local officials should be involved.

For larger dams and dams which present a threat to downstream development, or areas of critical concern, the design should incorporate some redundancy against the likely causes of failure. This could include filters or a zoned embankment.

All designs must be accomplished by qualified engineers and need to have an independent technical review, either internal or external.

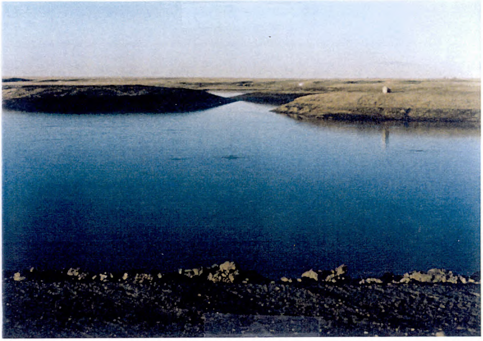

Photo # 1: Anita Reservoir prior to draining

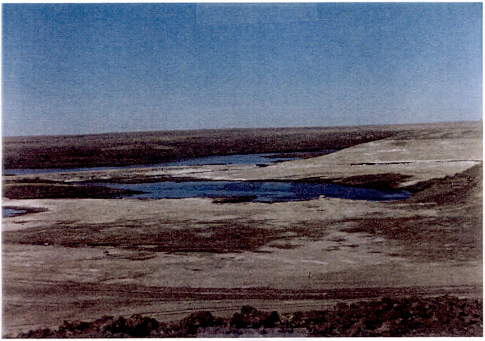

Photo # 2: Anita Reservoir after draining

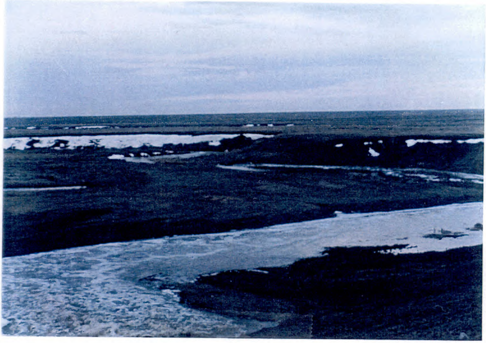

Photo # 3: Looking downstream (South) from dam
(Note water in outlet channel)

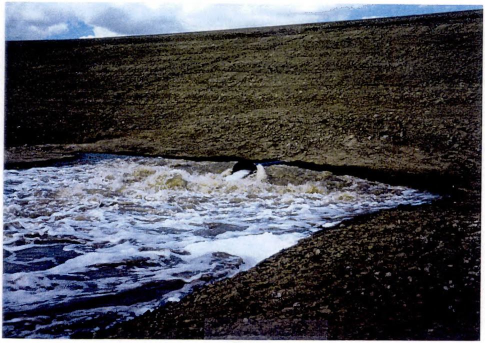

Photo # 4: Outlet pipe with water flowing around the pipe
(Water is spread by submerged gabions)

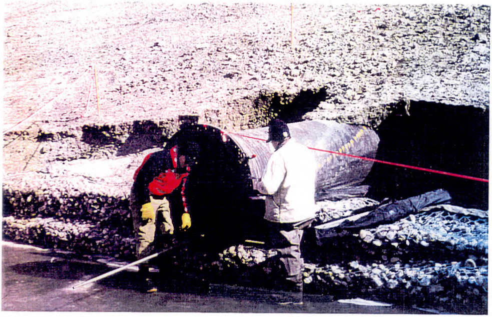

Photo # 5: Outlet pipe after reservoir was drained
(Note piping holes and gabions)

Photo # 6: Rip rap on upstream face of embankment
(Note outlet works in upper left)

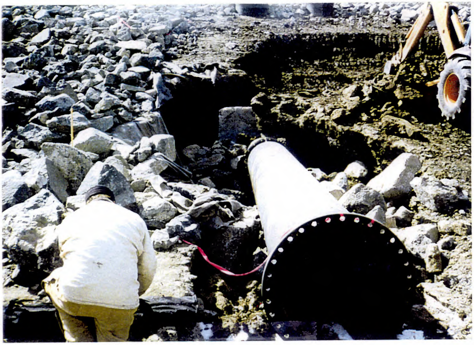

Photo # 7: Inlet pipe being excavated after dam failure
(Note piping hole next to cutoff collar)

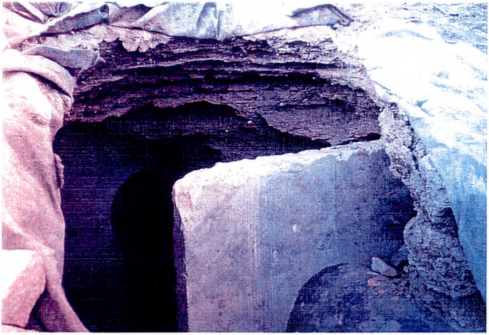

Photo # 8: Interior of piping hole next to inlet pipe